

Exhibit 21

(Amended)

SERPENTINIZATION: ORIGIN OF CERTAIN ASBESTOS, TALC AND SOAPSTONE DEPOSITS.

Sir: The problem of serpentinization, discussed by H. H. Hess¹ in this Journal, is an important contribution to the subject but is subject to criticism in certain parts; examination of a larger number of the Vermont talc and serpentine masses would have forced him to look for additional microscopic structures which would have altered materially most of his conclusions. Since many of these are of economic importance in the search for verde antique and talc, I offer the following contribution to correct certain inaccuracies that might become rooted in the literature.

Hess holds (p. 639) that,

The intrusions are concordant bodies, commonly lenticular in shape, individual lenses varying from 40 feet wide by 100 feet long to four times that size; but less commonly they occur as pinching and swelling sheets.

The Moretown lens—a moderate-sized one—is 5500 feet long by 500 feet wide.² Most of the other statements to which I do not subscribe arise from lack of sufficient size range in ultrabasics examined, and omission of mapping distribution of unchanged ultrabasic, serpentine and talc. Specifically, the following conclusions seem out of harmony with observed distribution of serpentinized and steatitized masses in Vermont ultrabasics:

1. Amphibole is an early mineral in the talc deposits.
2. Serpentine and chrysotile veins remain in the ultrabasic.
3. Serpentinization is due to causes originating within the ultrabasic.

Position of Amphibole in the Mineral Sequence.—Distribution of radiating actinolite in greater abundance along the walls than through the ultrabasics in Vermont, argues strongly against its early development. Coarse radiating actinolite appears independent of talc in only one ultrabasic out of over one hundred and fifty that have been mapped. (Other amphiboles are distributed irregularly through many of the serpentines; they follow the

¹ Hess, H. H.: Serpentinization: Origin of Certain Asbestos, Talc and Soapstone Deposits. ECON. GEOL., vol. 28, pp. 634-657, 1933.

² Bain, G. W.: Chrysotile Asbestos; II, Chrysotile Solutions. ECON. GEOL., vol. 27, p. 291, 1932.

serpentine-chlorite stage and precede the talc stage). This actinolite is found only in those masses that have been moderately to completely steatitized. This general rule applies to ultrabasics ranging from one in Westfield which has no talc, to those extreme examples in Weathersfield and in Rowe, Mass., where the entire mass is steatitized and parts are changed to hornblende schist.

The Holden Soapstone quarry is not a good place to study steatitization. An amphibolitized andesite cut by acid dikes forms part of the wall. Exposures of soapstone are poor and the steatitized mass may be altered from this amphibolite rather than from a typical ultrabasic. The soapstone is a massive chlorite rock partly replaced by rosettes of needle-like talc crystals. Hess regards these as pseudomorphs after amphibole (p. 644). The evidence is not conclusive at the Holden quarry, but a deposit south of the Randolph Gap road eastward from Rochester has similar radial talc in similar massive chlorite along the wall of the ultrabasic. Crystal cross-sections resemble those of an amphibole; sections parallel to the length of the acicular talc show "ghost" outlines of chlorite flakes and cleavage "ghosts" continuous with those in bordering chlorite. This indicates direct alteration of the chlorite to acicular talc along the line of growth of the talc crystal; the form is the talc growth form and not an amphibole replacement which it resembles. This acicular form of talc has a remarkably limited size of cross-section—up to one millimeter—where it occurs in chlorite. The radial actinolite ranges from 0.01 millimeters to 30 millimeters in cross section. If the talc is pseudomorphous after actinolite, size range in the two minerals ought to be comparable.

Talc from the Vermont Mineral Products mine is pierced by extremely delicate sprays of actinolite needles; each spray concentrates into a single crystal and these radiate from a base of biotite or chlorite wall or horse. Several very perfect, unbroken, delicate needles were separated from the talc. Conspicuous folding in the talc appeared on the smooth amphibole contact plane; the delicate actinolite would have been broken had it antedated the crumpling. Likewise, amphibole in the Randolph Gap ultra-

basic is undeformed and cuts across a schistosity in the older chlorite and serpentine. In each case a period of minor deformation preceded the actinolite introduction, and followed the serpentine, chlorite and talc formation. The weight of evidence still seems to favor a rising-temperature mineral sequence of serpentine or chlorite, talc, actinolite or biotite, and lastly hornblende or muscovite.³

Limitation of Distribution of Chrysotile Veins.—As Hess states (argument 3, p. 649) “the chrysotile veins are limited to the ultrabasic”; but chlorite veins, essentially similar to the chrysotile veins in the ultrabasic, appear around the Trowers Lake body in southern Quebec, and about the Moretown and upper East Granville talc deposits in Vermont, where the wall-rock is approximately similar to the ultrabasic in competence. It was suggested that the paucity of veins outside the ultrabasic is due to relative competence of the two rock types. This wider distribution of veins of the chrysotile system weakens the argument for an endo-metamorphic origin of serpentine.

Distribution of Serpentinization.—During the years 1928–30 I mapped the distribution of talc, serpentine and unchanged saxonite and dunite in more than 150 bodies extending from Eastman, Quebec, to east of North Adams, Mass. Masses approximating a half-mile long by 300 feet wide or larger are the only ones where the entire rock has not been changed. Serpentinization has been cited as limited to borders of fractures of tectonic origin;⁴ serpentine in the center of the peridotite, shown on Keith's map,⁵ lies along a highly fractured zone, and the verde antique or serpentine at Moretown occurs only in the most fractured part of that great lens. Alteration of the saxonite is absent or incomplete outside the fractured zones. As stated by Hess (argument 2, pp. 648–649) serpentinization bears no relation to the borders of the ultrabasic; but from the above it is evident that it does bear a very definite relationship to fractured zones in the

³ Bain, G. W.: *Op. cit.*, pp. 292, 295.

⁴ Bain, G. W.: *Op. cit.*, p. 284.

⁵ Keith, S. B.: Chrysotile Asbestos; I, Chrysotile Veins. *ECON. GEOL.*, vol. 27, p. 178, 1932.

saxonite and is incomplete outside of them. These fracture zones post-date crystallization of the ultrabasic by a considerable period.

Hydrothermal Origin of Serpentine.—Hess states (argument 5, p. 650) that:

Perhaps fifty hydrothermally altered (steatitized) ultrabasics were examined, and in every case chlorite, not serpentine, was developed.

From the discussion it is to be inferred that these ultrabasics were in Vermont. If anyone will take me to an ultrabasic in Vermont, and if they will exclude one small body in Westfield and one in North Troy, I will take them to a talc body in it. This seems to conflict with the statement that serpentine is not developed in steatitized ultrabasics.

At another place (argument 4, p. 650) Hess admits magnetite as one of the minerals of the serpentinization process but makes chlorite an index of hydrothermal alteration. Magnetite in verde antique serpentine does not polish satisfactorily, and I have been called upon to study its occurrence in this type of stone. Although every slab of verde antique produced has not come to my attention, those I have studied have a rim of chlorite around all magnetite grains. The magnetite and chlorite seem to have the same origin, whatever that may be; generally it seems to be a change that accompanies serpentinization and is related to the alteration of serpentine to talc.

Chlorite is very abundant in the walls of the ultrabasic adjacent to the talc deposit but the best quality of verde antique serpentine borders this talc-chlorite-carbonate zone. These close associations in distribution and sequence of development in rocks ranging from dunite to pyroxenite indicate to me that serpentinization, steatitization, and development of amphibole are not related to deuteric activity of the parent magma but are later hydrothermal changes that advance into the ultrabasic from solution channels, in the order mentioned. Certainly Hess' arguments 2, 3, 4, and 5 seem to fail when subjected to the test of specific cases.

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